

Intelligent Data Processing and Analysis During the Engine Test

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Abstract—Aircraft engines are equipped with a huge number of sensors that generate thousands of signals. One of the most important problems, especially during testing, is that the volume of this data is so large that experts are no longer able to process this data. Today, the direction related to the intellectualization of data processing and analysis methods is developing intensively. Intelligent data analysis systems are designed to minimize the effort of the decision maker in the process of data analysis, as well as in configuring analysis algorithms. Many intelligent data analysis systems allow not only to solve classical decision-making problems, but also to identify cause-and-effect relationships, hidden patterns in the system being analyzed. The article deals with the tasks of intellectual processing and analysis of data from the electronic control system (ECS) unit during engine testing. Using machine intelligence methods, the cause-and-effect relationships and regularities of the parameters of the turbojet engine were identified, and a large amount of data was analyzed. The results of data mining will be used for further informed decision-making and automation of the expert's analytical activities.

Keywords—machine intelligence, principal component analysis, cluster analysis, electronic control system, turbojet engine, data analysis system

I. INTRODUCTION

Today, the direction associated with the intellectualization of data processing and analysis methods is developing intensively. Intelligent data analysis systems (IDAS) are designed to minimize the efforts of the decision-maker in the process of data analysis, as well as in setting up analysis algorithms. Many IDAS allow not only to solve classical decision-making problems, but also are able to identify cause-and-effect relationships, hidden patterns in the system being analyzed.

The electronic engine control unit receives, processes, and controls systems and sensors that affect both the operation of the engine and the secondary elements of the engine during the entire operation of the engine.

A large number of tests are performed to identify patterns and causes of deviations and problems. The duration of the tests is directly related to the test methods, as well as to the hardware and software used to record information during the flight and analyze their materials. An effective solution to problems related to determining the necessary characteristics includes preliminary calculations, analysis of flight test

materials, accompanying modeling, and a combination of these methods to obtain integral estimates [1-3].

The general block diagram of the organization of tests is shown in the figure 1.

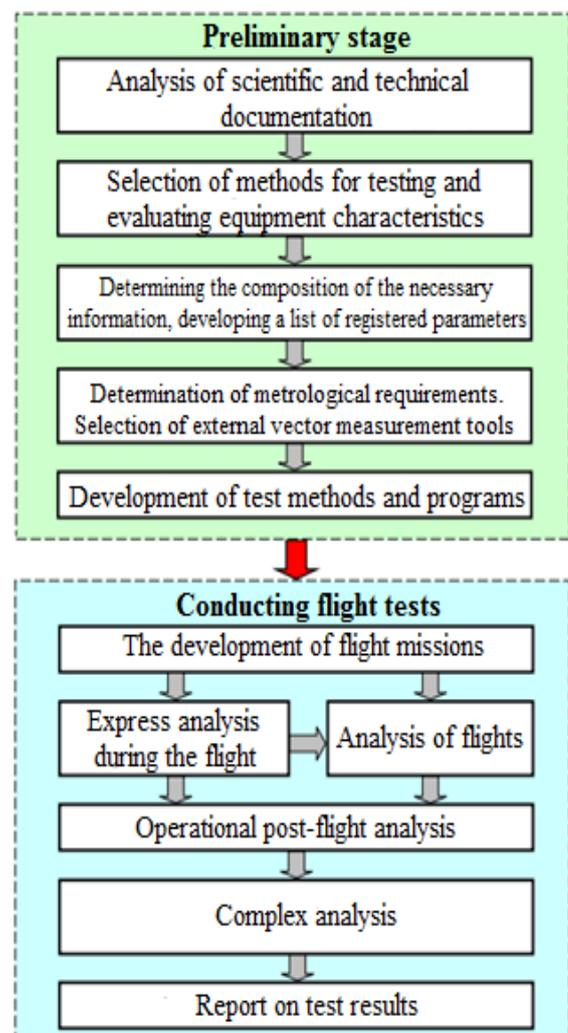


Fig. 1. Structural diagram of the organization of tests

Therefore, the purpose of the work is to analyze data on the engine and ECS unit states during test flights, which

allows us to identify the causes that affect the engine performance and reduce time costs.

To achieve this goal, you must solve the following tasks: to analyze the existing methods of machine intelligence; to consider the engine and its ECS as objects of research; to develop algorithms for the process of intelligent data processing and the formation of a data analysis system (DAS).

The object of research is a turbojet engine and an electronic engine control system unit.

The subject of research is data analysis methods.

II. TURBOJET ENGINE AND ENGINE CONTROL SYSTEM

Despite the simplicity of the design, the turbojet engine is a complex system that is almost completely controlled by "smart" automation. The pilot sets the necessary "thrust" using only one lever, while the "electronic control system", operating with the indications of numerous sensors and setting commands to the actuators, performs the rest of the work, selecting the engine parameters for the desired thrust indicators [4-6].

The electronic engine control unit receives, processes, and controls systems and sensors that affect engine operation.

The ECS block must:

- make the analog settings;
- to receive discrete signals;
- issue control signals and commands.

The main engine control modes set by the engine control lever (RUD): start, low gas (MG), warm-up (0.3 max), pickup, 0.7 max, training max, max. The modes that we are most interested in, and which revealed the greatest vibration in the static position of RUD: low gas (MG), heating, max.

III. DESIGNING A DATA ANALYSIS SYSTEM

To develop a data analysis system, it is necessary to develop an algorithm for designing and operating the engine (figure 2), for more accurate step-by-step analysis.

Step 1. Selection and rationale of analysis methods.

Intelligent systems are able to synthesize a goal, make a decision to action, provide action to achieve the goal, predict the values of the parameters of the result of the action and compare them with real ones, forming feedback, adjust the goal or control. IS can solve intelligent problems, recognize situations (images), learn concepts and skills, form a model of the situation (problem being solved), plan behavior (make a decision), determine control actions and carry out their processing. The possibilities of practical implementation of IS for solving various problems depend on the performance of modern computers.

For clarity, the influence of parameters on engine operation, the Data Mining method was used, which includes all kinds of classification, modeling and forecasting methods.

All Data Mining methods are divided into two large groups according to the principle of working with the source training data. In this classification, the upper level is determined based on whether the data is saved after Data Mining or whether it is distilled for later use [7-9].

Step 2. Principal component analysis.

At this stage, the construction of the main components is performed. For this, variables are set that should be involved in the analysis. A summary of the results of the analysis by the method of principal components is presented in figure 3.

The principal component method transitions to a new coordinate system in the original feature space, which is a system of orthonormal linear combinations.

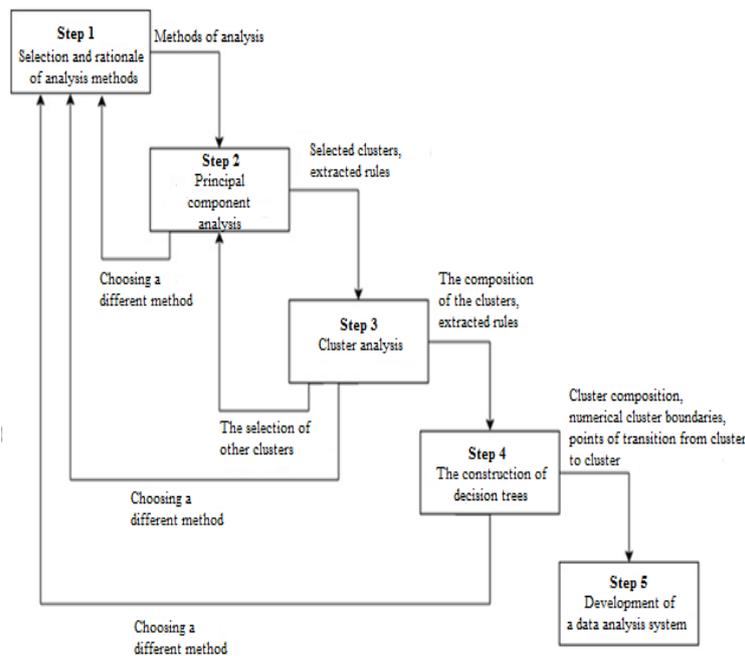


Fig. 2. Algorithm of stages of data analysis system design

The principal component method consists in finding a set of p orthogonal vectors in the n -dimensional source data space; since $p \ll n$, this makes it possible to move to a reduced feature space. The effectiveness of the method consists in minimal distortion of the geometric structure of points (objects) when they are designed into a space of a smaller dimension [10,11].

Principal Components Analysis

Data variables:

- Col_1
- Col_2
- Col_3
- Col_4
- Col_5
- Col_6
- Col_7
- Col_8
- Col_9
- Col_10
- Col_11
- Col_12
- Col_13
- Col_14
- Col_15
- Col_16
- Col_17
- Col_18
- Col_19
- Col_20
- Col_21
- Col_22
- Col_23
- Col_24
- Col_25
- Col_26
- Col_27
- Col_28
- Col_29
- Col_30

Data input: observations

Number of complete cases: 20291

Missing value treatment: listwise

Standardized: yes

Number of components extracted: 3

Fig. 3. Summary of Principal Component Analysis

Since there is a rather large amount of data in the work, the methods of component and cluster analysis were accordingly selected.

Using the method of principal components, it is seen that for given variables that are involved in the analysis, the main components (MC) are formed. Next, information is provided on the eigenvalues of the principal components (eigenvalue), ordered in magnitude; percent of variance attributable to each highlighted main component; cumulative percentage of variance (cumulative percentage) [12,13].

The amount of main components depends on the accumulated percentage of variance. Next, the dependence of the signs on the MC is determined. By calculating the

coefficient of information content K_i , a set of influence of signs is formed for each group of companies.

Figure 4 shows a fragment of a two-dimensional scattering diagram, which is formed using three tests.

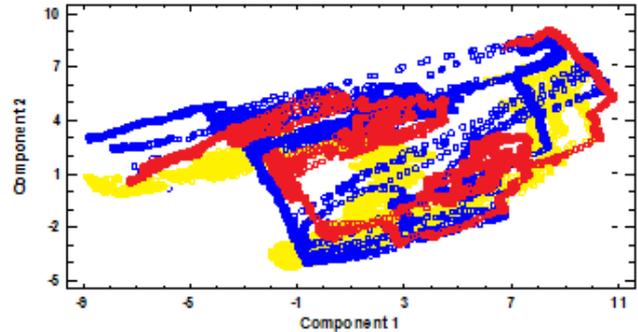


Fig. 4. Two-dimensional scatter plot

Step 3. Cluster analysis.

Cluster analysis is a method of classification analysis; its main purpose is to break down the set of objects and features under study into groups or clusters that are homogeneous in a certain sense. This is a multidimensional statistical method; therefore, it is assumed that the initial data can be of significant volume, i.e. the number of objects of research (observations) and the signs characterizing these objects can be significantly large [14,15].

Cluster analysis is carried out using the Ward method, City-block metric.

The following data were selected as signs (engine parameters), characterizing the state of the turbojet engine during the flight, every 0.25 seconds: GT - reduced fuel consumption; N_{vd} - reduced rotor speed of the high-pressure compressor; N_{nd} - reduced rotor speed of the low-pressure compressor; J_{Gt} - indicators of the provisions of the metering element of the fuel system; J_{na} - an indicator of the positions of the guide vanes; P_{bx} - reduced air pressure at the engine inlet; $P_{m_{bx}}$ - reduced oil pressure at the engine inlet; T_{vh} - reduced air temperature at the engine inlet; T_{nd} - the reduced temperature of the gases behind the low-pressure turbine, etc.

A fragment of the clustering results is presented on the scatter diagram in the space of signs $J_{Gt_{pr}}$ and $G_{t_{pr}}$ (figure 5) [16-18].

The diagram shows how the studied observations are grouped on the plane of two variables $J_{Gt_{pr}}$ and $G_{t_{pr}}$. Each cluster is indicated on the diagram by its own symbol.

Based on the implementation of component and cluster analysis, decision trees are built.

Step 4. The construction of decision tree.

Decision trees - a method that allows you to represent the analyzed data in the form of a set of if-then rules, presented in the form of a hierarchical structure - a tree.

The result of constructing a decision tree in the form of a structured record is presented in figure 6.

The constructed decision tree consists of n branches. Each branch of the decision tree ends with the class number to which it leads.

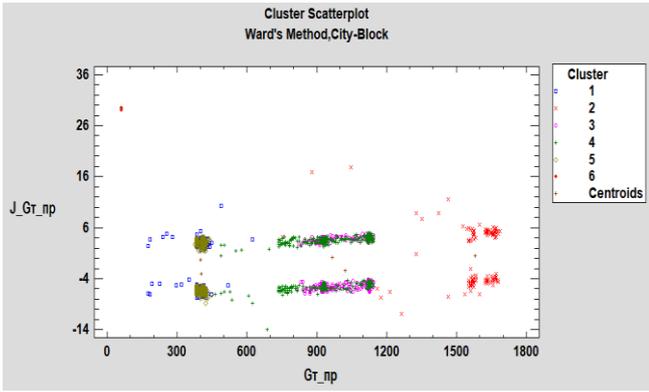


Fig. 5. Two-dimensional scatter plot

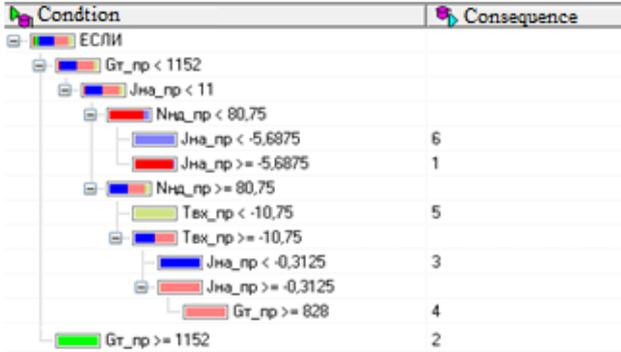


Fig. 6. Two-dimensional scatter plot

№	Rule number	Condition			Consequence	
		Index	Sign	Value		
1	1	9.0	Gr_np	<	1152	6
		9.0	Jna_np	<	11	
		9.0	Nnd_np	<	80,75	
		9.0	Jna_np	<	-5,6875	
2	2	9.0	Gr_np	<	1152	1
		9.0	Jna_np	<	11	
		9.0	Nnd_np	<	80,75	
		9.0	Jna_np	>=	-5,6875	
3	3	9.0	Gr_np	<	1152	5
		9.0	Jna_np	<	11	
		9.0	Nnd_np	>=	80,75	
		9.0	Tax_np	<	-10,75	

Fig. 7. Extracted classification rules

Actually	Classified					Total
	1	2	3	4	5	
1	2504					2504
2		6827				6827
3			3326			3326
4				1243		1243
5					2728	2728
Total	2504	6827	3326	1243	2728	16628

Fig. 8. Classification table

Step 5. Development of a data analysis system.

To develop a model for analyzing data on the functioning of turbojet engines, it is necessary to develop a knowledge base that will be compiled by the results of component, cluster analysis and construction of decision trees.

The block diagram of the implementation of the data analysis system based on the database and the knowledge base is shown in figure 9. The initial sample of data taken from the ECS block is stored in the ECS database. The generated knowledge, using the methods of the main components, cluster analysis and the decision tree, is transferred to a logical inference system, which performs logical inference and forms the rules by which a decision is made on whether technical requirements and automatic control systems are in accordance with the required engine parameters.

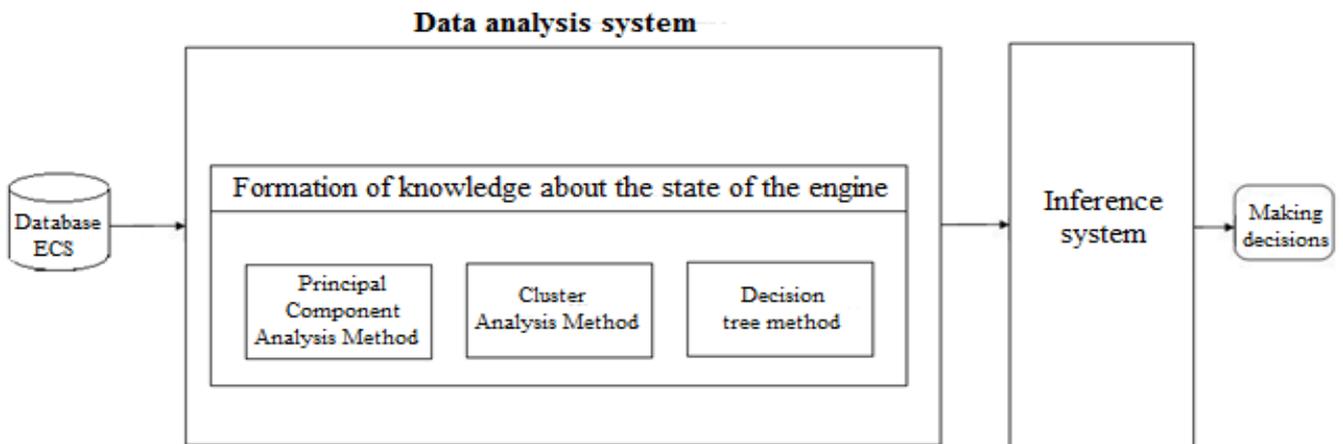


Fig. 9. Block diagram of the implementation of the data analysis system

IV. CONCLUSION

In this paper, we analyze the problem area, consider the turbojet engine and its electronic control systems as objects of study, perform the structuring of the test process as well as the data processing process, develop an algorithm for the process of intelligent data processing and the formation of a data analysis system, analyze the existing methods of artificial intelligence.

Based on the analysis, it is proposed to use for the intelligent analysis of the state data of a turbojet during test flights the methods: component, cluster analysis, construction of decision trees.

The results of data mining will be used for further informed decision-making and automation of the expert's analytical activities [19-25].

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